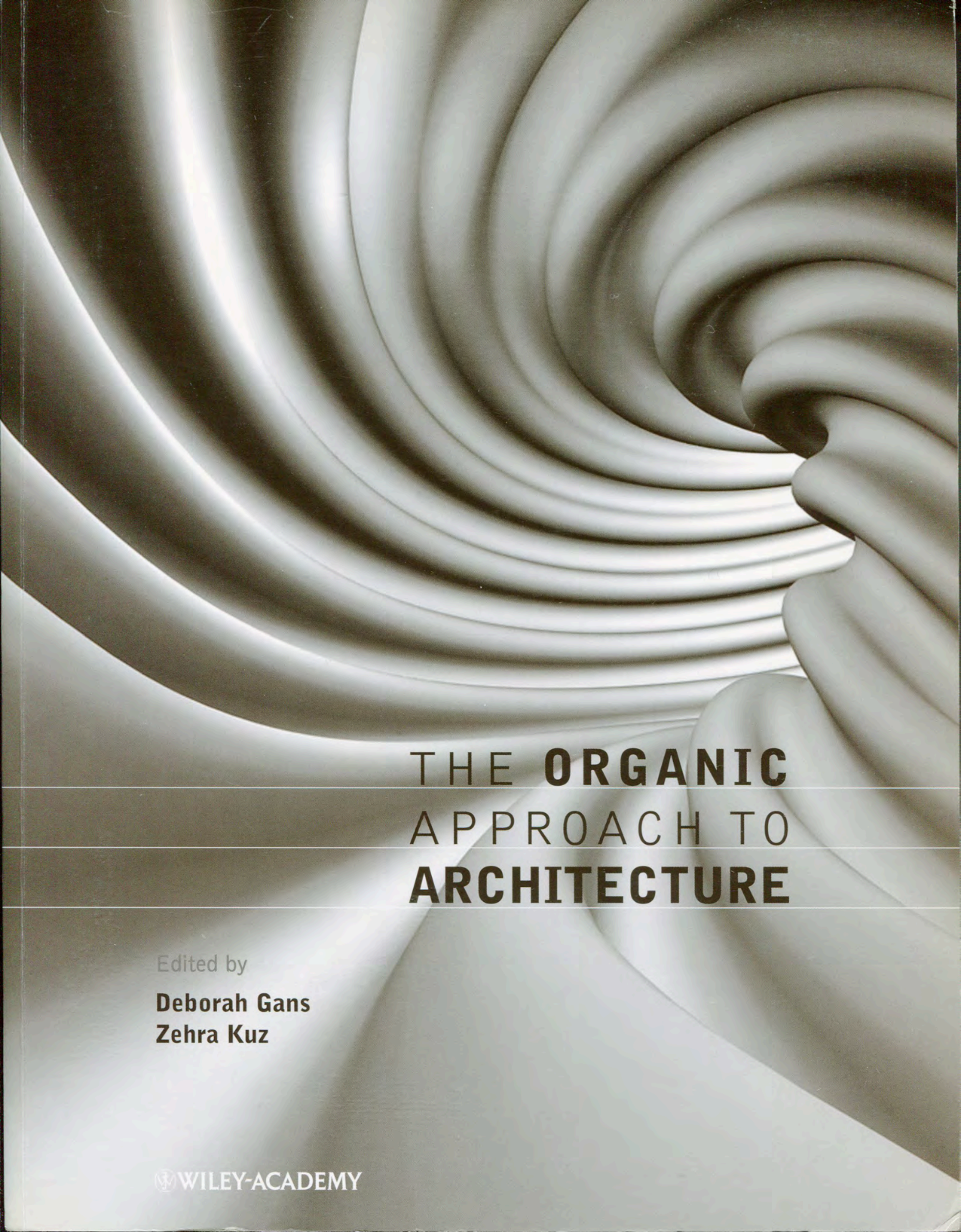

THE **ORGANIC** APPROACH TO **ARCHITECTURE**

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Genomic Architecture

Introduction

Genomic architecture is based on the manipulation of the *architectural genome*. Like its biological counterpart, this genome is universal and encompasses all architecture – past, present and future. At its root, this genome is defined by a unified *morphological genome*, a universal code for all morphologies – natural, human-made and artificial. *Morphogenomics*, a possible new science, deals with morphological informatics. It includes mapping the morphological genome as a basis for generative morphologies that underlie the shaping of architectural space and structure. Once mapped, the morphological genome will need to be layered with other genomes (also requiring mapping) to cover different aspects of architecture: physical (for example, materials construction technologies) sensorial, cognitive and behavioural. Genomic architecture, based on the layered genome, encompasses an integrated world of artificial architecture' (used in the same sense as artificial intelligence' and artificial life'), a world of complexity evolving in parallel with the natural world. It is a morphologically structured network of information that determines architectural taxonomies and phylogenies, permits digital manipulation of form in the design process and enables mass customisation in digital manufacturing.

Limits of Organic Architecture

The meaning of the term organic architecture' which draws its inspiration mostly from biology keeps evolving with increasing knowledge of nature combined with foreseeable technologies. As new technologies emerge, architecture becomes *more* organic in its scope, intent and realisation. The upper limit to this sort of biomimicry would be biology itself. Buildings would grow [1] respond, adapt and recycle, they would self-assemble and self-organise, they would remember and be self-aware, they would evolve and they would reproduce and die. Organic architecture, were it to attain biology would design itself. It would also perpetuate itself. Architecture would then become 'life' and, paradoxically buildings would no longer need architects. Organic architecture, in this limited case scenario, would also define the end of architecture (as we define architecture now).

Extrapolating from projected technologies of the future,[2] a scenario like this one is quite possible, even inevitable but it is flawed for two reasons. First, biology as a goal for organic architecture assumes that such a biology (namely, *existing* biology) is frozen in time since it is based on 'life' as we know it presently. Extrapolation of architecture from *present* biology ignores *past* and *future* biologies. Nature's ongoing experiment comprises structures that are extinct, structures that exist now and structures that have yet to appear.[3] The definition of organic' must thus encompass *all* biologies: past, present and the future. Second, it ignores the creation of the *new* for example new materials (new chemistries) not found in nature, new technologies not found in nature and new organisms (based on known or new biologies) not existing in nature. Besides new natural biologies, the term organic' must thus include *artificial biology* as well. This is where the line between human designs and those made by nature becomes a continuum.

Unifying Laws

What unites the natural and the human-made (including the artificial) are fundamental laws, the *laws of nature*. Our knowledge of nature and human-made constructions evolves so that these laws become increasingly more encompassing, tending towards the natural upper limit of a single unifying law for everything (as in the current search in physics, for example) Whether this limit is attainable is an open question. The natural and the artificial are facets of organic architecture that are joined at this fundamental level. This is true of biology and buildings. The morphologic possibilities within these two worlds fall within a single *morphological universe*[4] governed by unifying laws of form that are common to both.[5] It is governed by the mathematics of space, structure and form. When physical constraints (size material, movement, weight, stability, building method or forming process, etc) are imposed on form, this universe shrinks through the elimination of mathematical structures that are physically unrealisable. The physics and chemistry of form delimits the morphological universe.

Hyperuniverse of Form[6]

Imagine a universe of all possible morphologies, a universe that includes all past, present and future structures. A universe that is infinite and open-ended, and one that has a fractal hierarchy composed of recursive levels within levels. A universe that one can access and navigate through in any number of ways from any level. A universe where each structure (and each type of architecture) can transform from one to another in a continuum of space and time, both within and between levels. Using simple orderly structures as a starting point for more complex structures, the results thus far suggest that this universe is highly structured.[7] [8] It has an underlying structure a meta-structure, which can be continually modelled and extended in higher dimensional space (hyper-space) This metaspace defines the HyperUniverse of Form.

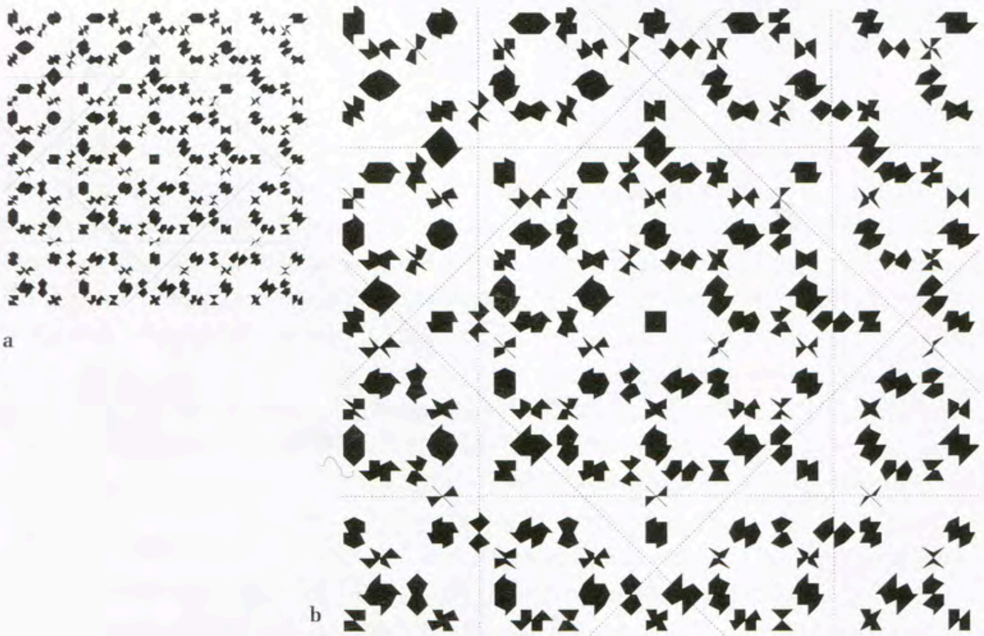
In this morphological hyperuniverse, different types of morphings[9] are encountered. Simple forms can transform to complex, regular can transform to irregular, periodic to nonperiodic, symmetry to asymmetry static can become dynamic, solid can become void, tension can become compression, inorganic (geometry) can become organic (geometry) and so on, all in a continuous manner. In this universe of continuous transformations, all dialectics disappear. Within this universe, topologies are created and destroyed. elements (points, lines planes and cells) are added and subtracted or simply appear and disappear· open lattices transform to finite closed objects genus is created and transformed, closed becomes open, and inside becomes outside; and Euclidean space changes to non-Euclidean space. This universe is a continuum where every form can transform to another continuously. This metamorphosis follows systematic transformation pathways within the hyperspace. The structures can also undergo points of singularities in this space to enable dramatic topological transformations. Further, this universe itself evolves and grows as new morphological possibilities are discovered or invented by humans or nature.

Morphogenomics

Each structure within the hyperuniverse has a unique address. The code, defined by symbols (for example, numbers) determines this address and defines a structure uniquely The numbers have a parametric meaning, both topologic and geometric. The morphological code (morph-code)[10] defines the *genetic code of form* and serves as the basis for a unified *morphological genome*. The genetic code of form, when layered with other aspects of architecture, defines the *genetic code of architecture* as the basis for the *architectural genome*. In a broader sense, the morph-code encodes all formal design possibilities in the natural, artificial and the human-made worlds.[11] In biological terms this is an epigenetic code that exists in parallel with the biological genetic code captured in the DNA sequences.[12] The morph-code leads to the possibility of *morphogenomics* mentioned earlier. It provides a formal tool in the design and manufacturing processes.

The morph-code can be manipulated to generate an endless variety of forms. Manipulating this code is the same as navigating through the hyperuniverse of form. Since any location within the hyperuniverse determines a unique form, a unique structure or a unique design solution, one can run through a myriad of solutions for a design problem through this navigation process and select the best possible solution. If needed, this solution can be easily altered (transformed) also through the same navigation process, to suit any changes in the design. Once a design is selected, it can be linked with digital manufacturing and assembly processes also similarly coded, to get a built structure.

The first example developed by the author 20 years ago along these lines was a pattern-code for generating Islamic and other geometric patterns.[13] Typing in a sequence of the code (alphanumeric, in this instance) yielded a new pattern on the computer screen. Though only a pen-plotter was used as the output device to make long scrolls of line patterns any device for marking, scoring, cutting or milling would have instantly linked it to pattern-making in other materials. The code provided a formal and technological tool for pattern-generation with obvious ramifications for designers, craftspersons and pattern-manufacturers in various fields (architecture, textiles, paper and various sheet material industries). It also provided the possibility of indexing all patterns within a unified digital taxonomic database as a universal (pan-cultural) pattern informatic system useful for historians, anthropologists and others interested in the evolution of pattern across cultures. Evolution of pattern would mean mapping the pathways of cultural patterns within the hyperuniverse. The same would apply to a chronological evolution of architectural form.

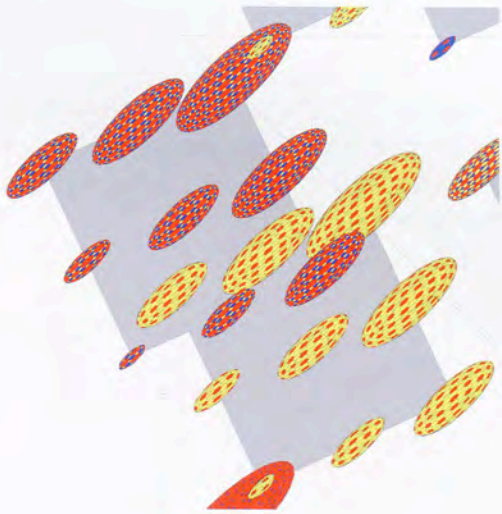


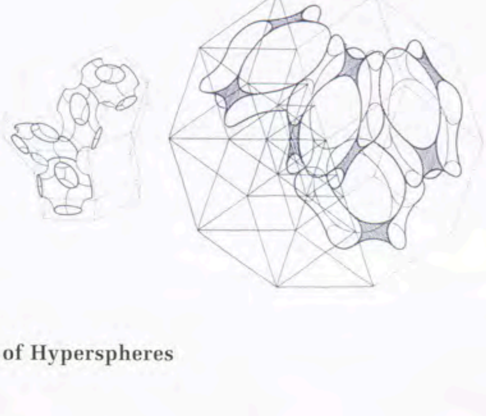
1.
Coded Squares at different scales (a and b)

Windows into the Hyperuniverse

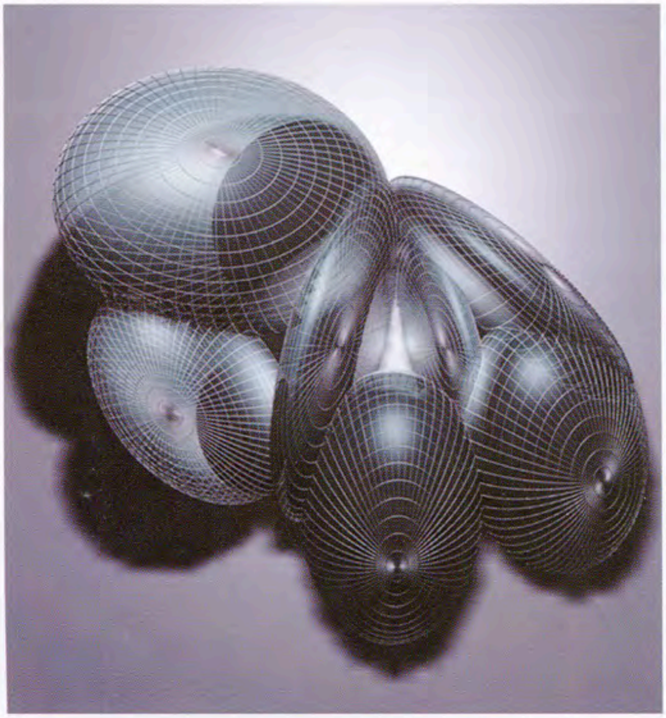
Zooming into this hyperuniverse through one window we see the world of coded squares in its many states all morphing from one state to another. **(Figure 1a and b)** When the individual squares are coalesced into a continuum, a pattern similar to Escher's celebrated metamorphic designs is obtained, with the difference that the result is a higher-dimensional analog of Escher, a hyper-Escher pattern.[14] Looking elsewhere into another window say into the special world of spheres we see all morphologically coded geodesic surface patterns, all intertransforming. **(Figure 2)** Fuller's geodesic domes are embedded in this part of the hyperuniverse, so are the various spherical fullerenes[15] and the spherical viruses. A peek into higher-dimensional worlds located in another part of the hyperuniverse reveals the many states of higher-dimensional space structures. This example is interesting as it suggests a self-similarity between structure and meta-structure. One example is a family of cells of hyperspheres and two curved variants of the cells of a six-dimensional cube, related to the well-known quasi-crystals in nature.[16] **(Figure 3)** And, so on.

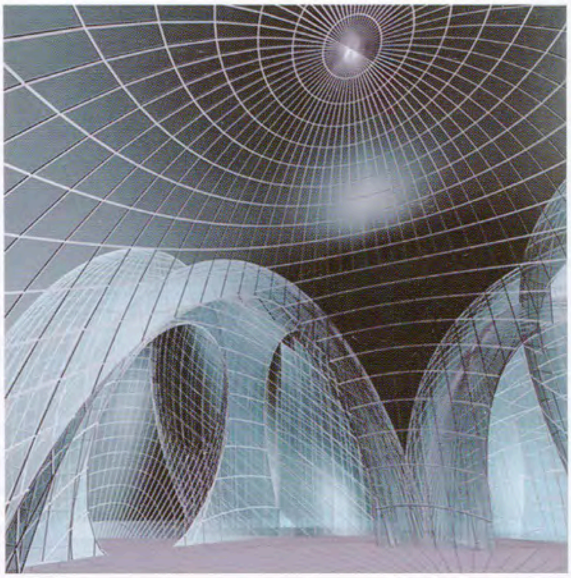
2.
Family of Geodesic Surface Patterns





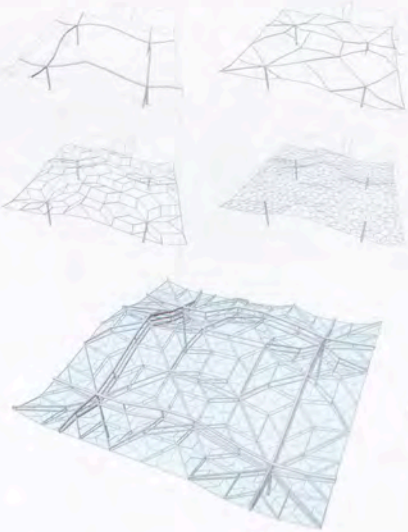
3.
Family of Hyperspheres





4.
Left and above
Spheroids

Navigating through the many hyperstructures in the hyperuniverse, one discovers interesting spatial possibilities for architecture. In *spheroids* intersecting volumes with varying tilts and embedded in six-dimensional space provide architectonic possibilities for varying functions (greenhouses, convention halls, etc) **(Figure 4)** In *fractal fold* a fractal geometry based on higher dimensions[17] defines an irregular roof suggested for a new assembly space within an existing building complex.[18] **(Figure 5)** This building system is interesting in that it permits irregularity from equal struts within a hierarchical structural system of increasingly larger and stronger elements.



5.
Left
Fractal Fold Roof

Bottom-Up Mass Customisation: The Milgo Experiment

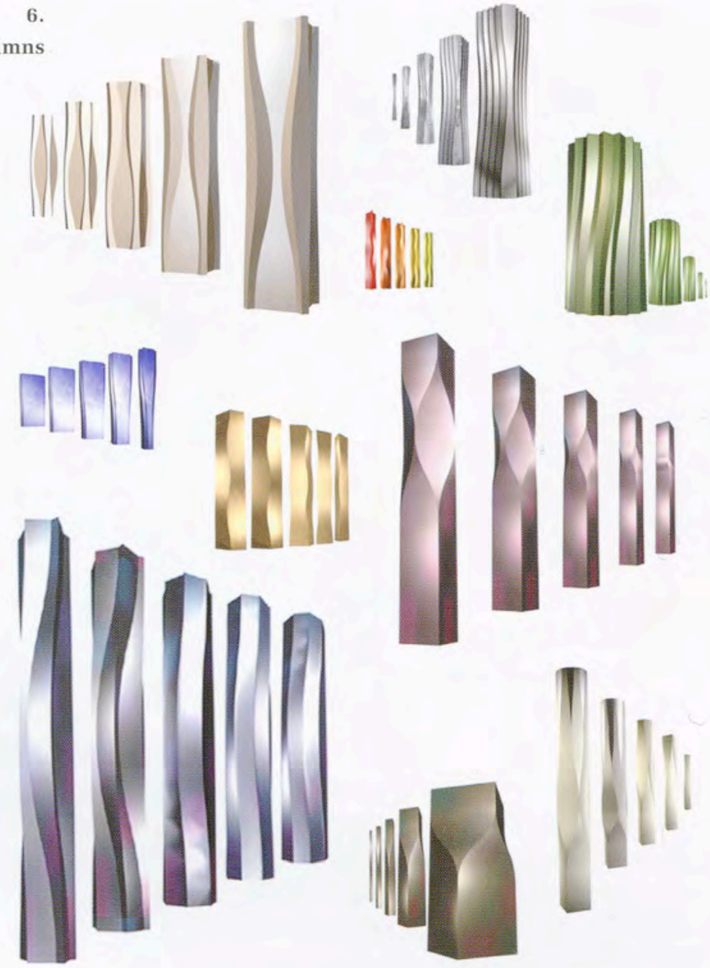
Five years ago we began linking morphology with manufacturing. Milgo Industrial Inc, a leading metal fabrication company for art and architecture, provided the opportunity to link shaping with making. We chose a single material, in this case sheet metal, as the medium for experimentation as it provided the possibility of shaping a surface to define architectural space and form. We wanted to modulate the stiff metal surface in various ways to make rigid curved surfaces without deforming' the metal. This way the sheet metal would preserve its 'integrity' and become what 'it wants to be' (to borrow Louis Kahn's words). It would also become stronger in doing so. By comparison, standard methods of forming sheet metal, for example, stamping, deep drawing, etc deform the metal sheet into desired three-dimensional shapes (as, for example, in the making of automobile bodies). We discovered a new type of forming which we have termed 'non-deformational bending' This forming process generates its own vocabulary of curved surfaces,[19] opening up a new window into a different part of the hyperuniverse.

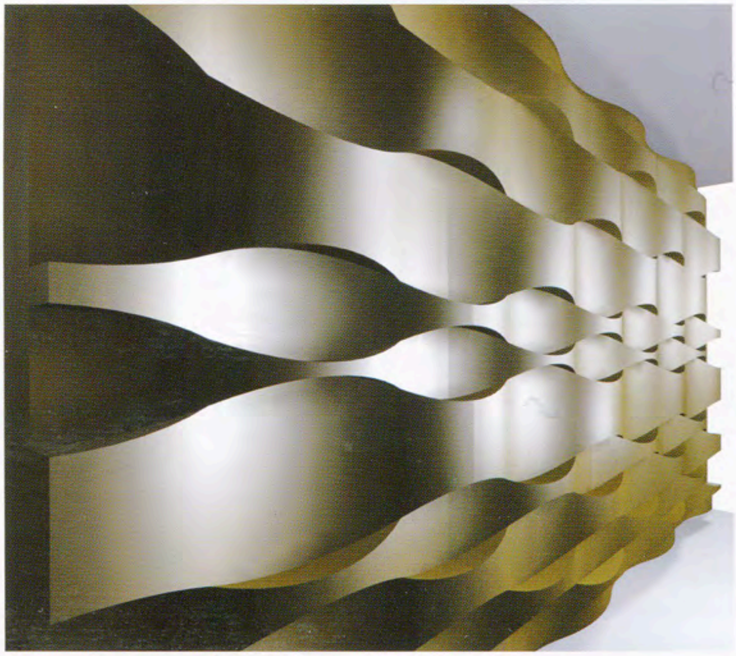
We used this forming technique to prototype a large body of architectural elements like columns wall and ceiling systems in sheet metal. The examples shown **(Figures 6 to 8)** are all developed from a morphologic algorithm and constructed from single sheets of metal using a single method of forming to obtain an endless 'variation on a theme' Generative morphology is combined with mass customisation. Just as each new design and each new variation we have been developing can be visualised by walking or flying through the digital hyperuniverse, we expect manufacturing technologies to be similarly automated to fabricate morphologically encoded one-of-a-kind designs. The *transforming columns* show iterations between groups of columnar structures, each group indicating a different direction in the hyperuniverse. **(Figure 6)** A *wall system* **(Figure 7)** and an irregular *ceiling system* reminiscent of zebra patterns and sand dunes **(Figure 8)** show panel morphologies derived and fabricated from the same shape and make' techniques and their details. (**Figure 9**) Currently we are extending our investigations to other types of design products including architectural structures, environments and spaces defined by continuous folded surfaces like *wave space labyrinth.* **(Figure 10)**

Unified morphological algorithms combined with digital manufacturing are ideally suited for mass customisation of design. As we relax the constraints of the material and forming methods that we have been using, related morphologies emerge and take us into another domain of the hyperuniverse. As new attributes and processes are added, new morphologies become immanent and form begins to become more fluid, to take one morphogenetic pathway as an example. **(Figure 11)** A digital environment based on a unified morphological genome would enable us to explore expediently and systematically the incredible diversity of forms that exist in nature, and beyond. The periodic table of chemical elements and the tables of elementary particles in physics are finite. In contrast, the *periodic table of form* is infinite and open-ended, the way biological genomes are, and the way the biological 'tree of life'[20] is. This enables new forms to be continually discovered within the ever-expansive morphological hyperuniverse.

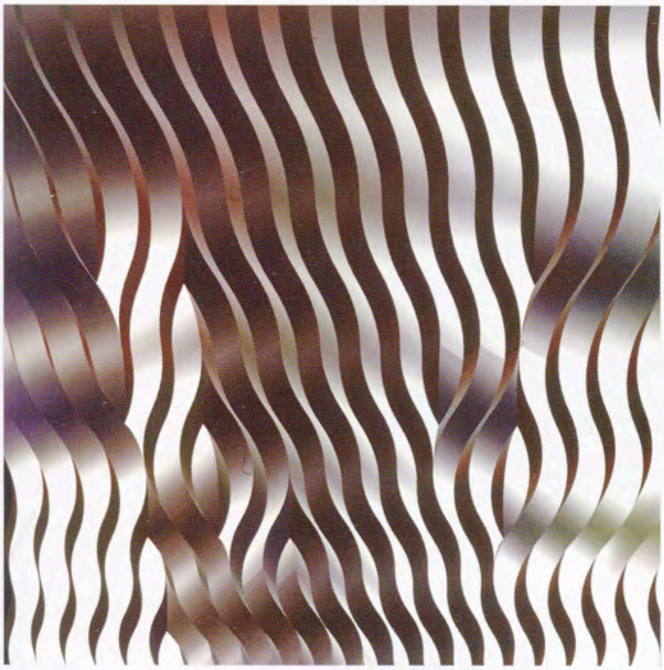
An interesting discovery in bioinformatics based on DNA sequencing is that, in many cases, different genes suggest different family histories for the same organisms suggesting that a more apt analogy for the history of life will be a net or a trellis' instead of a single universal tree.[21] Integrated hypernetworks of life will provide a theoretical upper limit to such trellises of life. As the new tree (or 'trellis') of life is mapped, the morphogenomics agenda proposed here provides

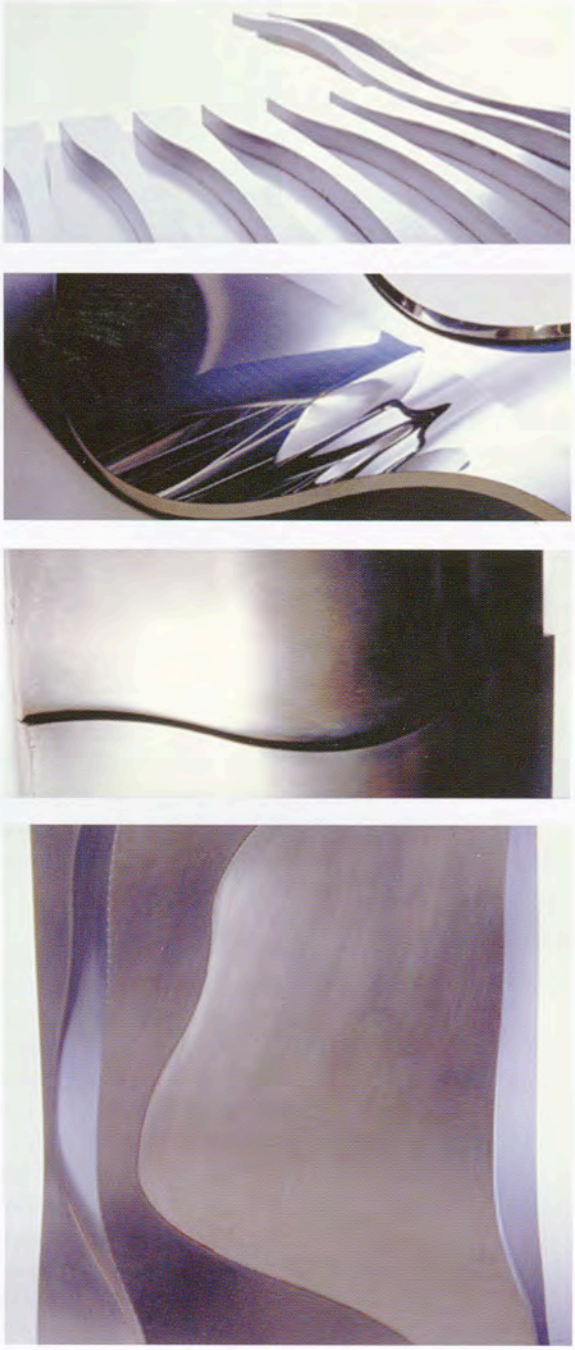
6.
Transforming Columns

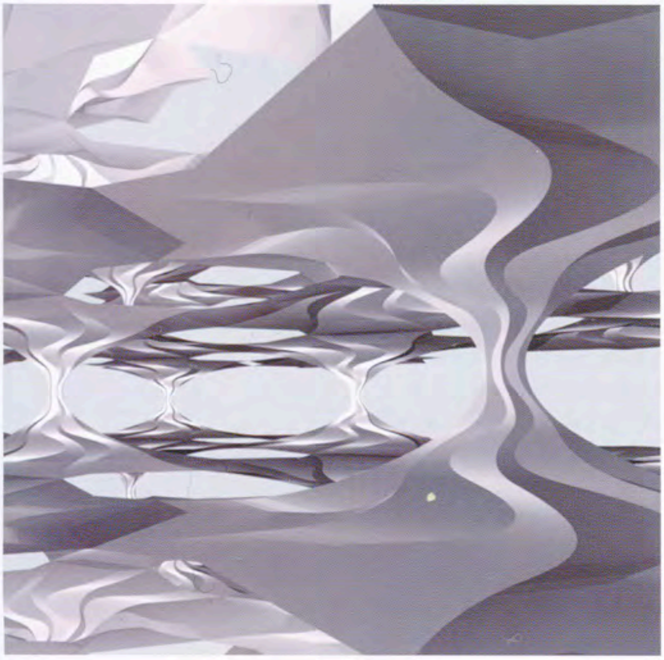




7
Wall System







8.
Top
Ceiling System

10.
Above
Wave Space Labyrinth

9.
Above
Prototype Details for Architectural Surfaces

11.
Morphogenetic Pathway

for the beginning of *artificial genomics* as a parallel to biological genomics. As the morphological genome begins to be linked with physical morphogenesis (not digital, as in the case of artificial life') and, in time, automorphogenesis (self-replication) [22] the bridge between the artificial and the natural will begin to disappear. In this scenario of genomic architecture, architecture and biology will become one, reaching the upper limit definition of organic architecture'

Notes

1. For origins of growing architecture, see William Katavolos, *Organics*, Steendrukkirj de Jong & Co (Hilversum) 1961 Vittorio Giorgini, 'Early Experiments in Architecture Using Nature's Building Technology' in H Lalvani (ed), *The International Journal of Space Structures*, 11 1 and 2 (1997).
2. See, for example, K Eric Drexler, *Engines of Creation*: *The coming era of nanotechnology* Anchor Books (New York), 1986, describing the future of building ultra-small and ultra-large objects atom by atom, Marvin Minsky, 'Will Robots Inherit the Earth?' *Scientific American* (October 1994) pp 109–113 where the author argues that they will, but as our 'mind-children (using H Moravec's term); Ray Kurzweil, *The Age of Spiritual Machines*, Penguin Books (London), 1999, where the author predicts that by 2099 there will no longer be any clear distinction between humans and computers. On the software end, there is sufficient literature on artificial life describing attempts at re-creating life 'in silico'
3. The paleontologist Stephen Jay Gould describes three possibilities in the landscape of imaginable lifeforms. 'can't work well 'can't work at all and 'just haven't been there yet' in Stretching to Fit' *The Sciences* (July/August 1998), pp 12–14.
4. Haresh Lalvani, 'Morphological Universe, Expanding the Possibilities of Design and Nature' unpublished manuscript, 1998, presented at the ACSA conference, 'Works of Nature: The Rhetoric of Structural Invention Dalhousie University, Nova Scotia, October 1998.

5. This universe encompasses structures ranging from the microscopic to the macroscopic, from living to nonliving, chemical to biological, and those realised by humans and (eventually) by machines. See D'Arcy Thompson's classic *On Growth and Form*, Cambridge University Press (Cambridge), 1942.
6. The author has been working on this hyperuniverse since the late 1970s (first published in 1981 see note 7). The term 'morphological hyperuniverse' in this context was first used in print in the author's contribution to *Cyberspace: The world of digital architecture*, Images Publications (Australia), 2001 p 38.
7 Haresh Lalvani, *Structures on Hyper-Structures*, Lalvani (New York),1982, based on the author's doctoral dissertation *Multi-Dimensional Periodic Arrangements of Transforming Space Structures*, University of Pennsylvania (1981), University Microfilms (Ann Arbor), 1982.
8. Beginning with orderly structures like tilings, polyhedra, geodesic spheres, space-fillings, etc this universe is being continually mapped and extended by the author to be more encompassing. This extension includes a variety of curved structures as well as architectural and structural morphologies. The formal languages of selected architects (eg, Gaudi, Wright, Calatrava, to name a few we have been studying) provide fertile material for such mapping.
9. In 1971 the author began experimenting with various types of morphings, some related to D'Arcy Thompson's celebrated method of transformations, and others inspired by different types of growth in nature (eg, crystal growth) and movement. During the mid-1980s, while Tom Brigham was experimenting with 'morphing' at the Computer Graphics Laboratory, New York Institute of Technology, the author, in collaboration with Robert McDermott and Patrick Hanrahan (also at CGL) was involved with a different type of continuous morphing, a structured morphing based on the reference in note 7
10. The term 'morph-code' (or shape-code) raises the interesting question for biological form, whether such a code is embedded in the DNA sequences or whether biological form is purely the result of nongenetic factors (eg, physical or chemical forces). If yes, then mathematics in nature must be a by-product of the physics and chemistry of life, raising the intriguing question of how the biological genetic code triggers the formation of highly mathematical structures like the logarithmic spirals of seashells, to give one example.
11 A universal morphological coding would work at different scales of magnitude from the microscopic to the macroscopic. For example, the generative classification of transformational polyhedra embedded within the hyperuniverse would apply to the formal classification of crystal morphology. The corresponding sphere-packed configurations would apply to atomic arrangements in physics and chemistry. In principle, the morphological system of continually transforming space structures lends itself to modelling the constructions of kinetic nanoscale deployable structures (see also note 22).
12. It is possible that genetic codes other than DNA, RNA exist though none have been found so far. These (theoretically possible) codes would define the upper limit for all forms of life in the universe. The study of *all possible* biologies will fall within the domain of *hyperbiology*
13. H. Lalvani, *Coding and Generating Islamic Patterns*, National Institute of Design, (Ahmedabad), 1982. Other articles by the author on this include: 'Pattern-Regeneration in S Doshi (ed), *An Impulse to Adorn*, Marg Publications (Bombay) 1982, and 'Coding and Generating Complex Periodic Patterns' *Visual Computer* **5**, Springer-Verlag (Munich), 1989, pp 180–202.
14. H. Lalvani, Structures and Meta-Structures' *Symmetry of Structure*, International Society for the Inter-Disciplinary Study of Symmetry (Budapest), 1989.

15. In 1993, the author suggested the existence of skewed fullerenes and hyperfullerenes (higher dimensional analogs of fullerenes) as part of the 'periodic table of fullerenes' at his presentation at the 3rd International Conference on Space Structures, University of Surrey, 1993. Parts of this table were later published in the proceedings of the conference Katachi U Symmetry, Tsukuba University, Japan, 1994. Relating to note 11 it is interesting that the skewed fullerenes have the same underlying morphology as that of some of the spherical viruses with skewed icosahedral symmetry. The morphological hyperuniverse transcends scale at its root level, though each subuniverse will bring its own specificity.
16. In 1984, when Schectman et al at NIST (National Institute for Standards and Technology) reported the existence of a rapidly cooled alloy of manganese and aluminum based on icosahedral symmetry, till then denied in crystallography, a new class of natural nonperiodic structures (termed 'quasi-crystals') opened up. Interestingly, nonperiodic structures were independently discovered in different fields: mathematics, physics, crystallography and architecture. The author's independent work during the period 1981–5, and subsequently, was amongst those within the field of architecture along with the works of Baer and Miyazaki.
17 This particular example, related to the Penrose tiling, is a projection from four dimensions. The dimensionality of the structure increases with the extent of subdivision of the surface and results in increasing irregularity.
18. This roof concept was developed in 2001 in collaboration with Maria Sevely and Archronica architects on their project for a pharmaceutical company.
19. US Patent No. 6,341,460.
20. A major effort is currently being planned for assembling the tree of life to construct a phylogeny of the 1 7 million described species of life.
21 Francis S Collins and Karin G Jegalian, 'Deciphering the Code of Life' in *Editors of Scientific American, Understanding the Genome*, Warner Books (New York), 2002 p 37
22. The idea of using morph-coded designs of Drexler's nanotech 'assemblers' and 'replicators (cited in note 2) is a more direct application of morphogenomics. Morph-coded shapes (and materials) that change from one to another using transformation pathways within the hyperuniverse can be constructed using Drexler's proposal for building atom by atom. On a related note, the author, in the early 1970s in an unpublished paper, had suggested achieving 'automorphogenesis' using genetically engineered bacteria as an alternative method of self-replication that relies on a biological process of building.

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